Marta Calvi
University of Milano Bicocca
and INFN

Summary: CKM Physics

$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

- Precise measurement of CKM elements
- Tests of unitarity
- Constraints from fit to UT
- Searches for NP

Disclaimer: it was a very rich session with 9 excellent talks, a lot of results could not be included in this short summary

Cecilia Tarantino

The Standard Model Fit

The experimental constraints:

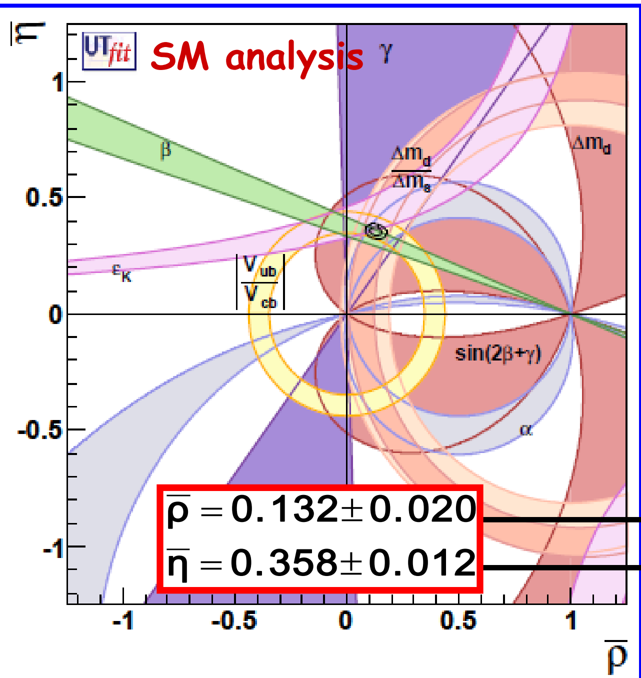
$$\varepsilon_K, \Delta m_d, \left|\frac{\Delta m_s}{\Delta m_d}\right|, \left|\frac{V_{ub}}{V_{cb}}\right|$$

⇨ relying on theoretical calculations of hadronic matrix elements

$$\sin 2\beta, \cos 2\beta, \alpha, \gamma(\quad 2\beta+\gamma)$$

⇨ independent from theoretical calculations of hadronic parameters

overconstrain the CKM parameters consistently



~16%

~ 3%

The UTA has established that the CKM matrix is the dominant source of flavour mixing and CP violation

From a closer look

Cecilia Tarantino

UTfit

From the UTA (excluding its exp. constraint) → Prediction

	Prediction	Measurement	Pull
$\sin 2\beta$	0.771±0.036	0.654±0.026	2.6 ←
γ	69.6°±3.1°	74°±11°	<1
α	85.4°±3.7°	91.4°±6.1°	<1
$\|V_{cb}\| \cdot 10^3$	42.69±0.99	40.83±0.45	+1.6
$\|V_{ub}\| \cdot 10^3$	3.55±0.14	3.76±0.20	<1
$\varepsilon_K \cdot 10^3$	1.92±0.18	2.230±0.010	-1.7 ←
$BR(B \to \tau \nu) \cdot 10^4$	0.805±0.071	1.72±0.28	-3.2 ←

PRECISION FLAVOUR PHYSICS

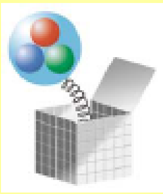
Vittorio Lubicz

Experiments 2010

$\vert V_{us}\vert f_+(0)$	0.21661 ± 0.00047	0.2%
$\dfrac{\vert V_{us}\vert F_K}{\vert V_{ud}\vert F_\pi}$	0.27599 ± 0.00059	0.2%
ε_K	$(2.228 \pm 0.011) \times 10^{-3}$	0.5%
Δm_d	$(0.507 \pm 0.005)\ ps^{-1}$	1%
Δm_s	$(17.77 \pm 0.12)\ ps^{-1}$	0.7%
$\sin 2\beta$	0.655 ± 0.027	4%

Lattice 2010

	Lattice 2010	2006
$f_+(0)$	0.5%	0.9%
F_K/F_π	0.9%	1.1%
B_K	5%	11%
$f_B\sqrt{B_B}$	5%	13%
$f_{Bs}\sqrt{B_{Bs}}$	5%	13%
—	—	—



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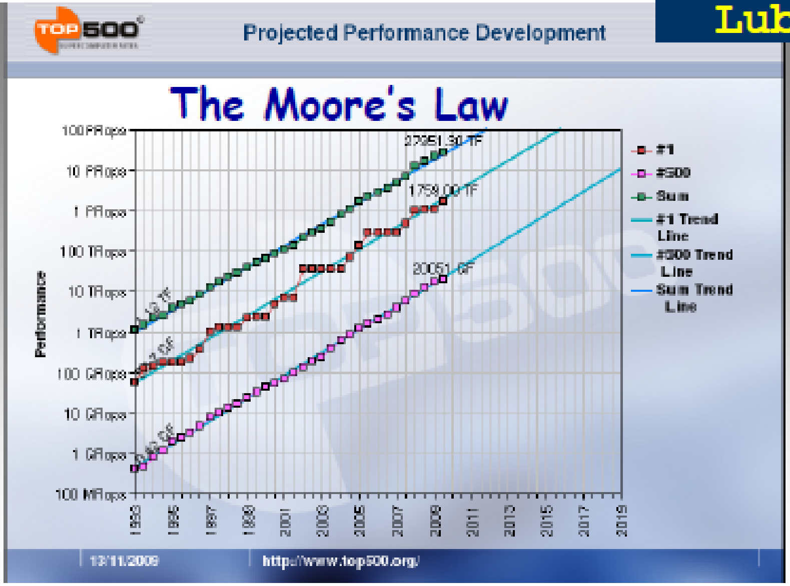
THE "PRECISION ERA" OF LATTICE QCD

1) Increasing of computational power

TeraFlops machines are required to perform unquenched simulations. Available only since few years.



2) Algorithmic improvements

CPU cost of a simulation (for Nf=2 Wilson fermions):

- Ukawa 2001

$$\text{TFlops-years} \simeq 3.1 \left(\frac{N_{conf}}{100}\right)\left(\frac{L_s}{3\ \text{fm}}\right)^5\left(\frac{L_t}{2L_s}\right)\left(\frac{0.2}{\hat{m}/m_s}\right)^3\left(\frac{0.1\ \text{fm}}{a}\right)^7$$

- Del Debbio et al. 2006

$$\text{TFlops-years} \simeq 0.03 \left(\frac{N_{conf}}{100}\right)\left(\frac{L_s}{3\ \text{fm}}\right)^5\left(\frac{L_t}{2L_s}\right)\left(\frac{0.2}{\hat{m}/m_s}\right)\left(\frac{0.1\ \text{fm}}{a}\right)^6$$

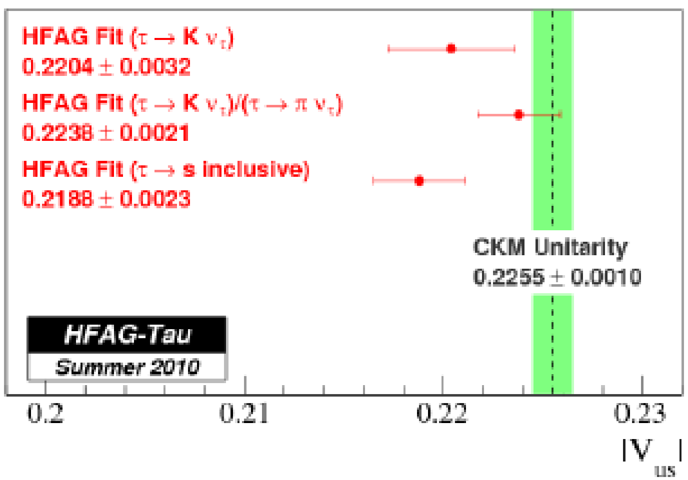
$M_\pi \approx$ 200-300 MeV ⟶ Light quark masses in the ChPT regime

$|V_{us}|$ and Charge Lepton Universality from τ Decays

In summary BaBar & Belle have measured 9 of the main τ strange branching fractions.

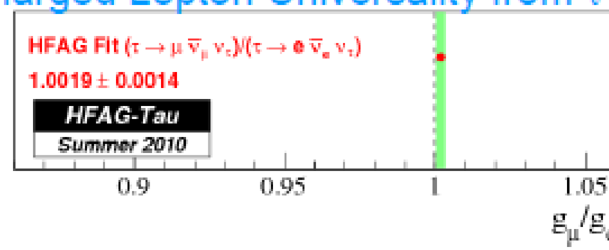
The results have been combined with previous τ measurements to extract:

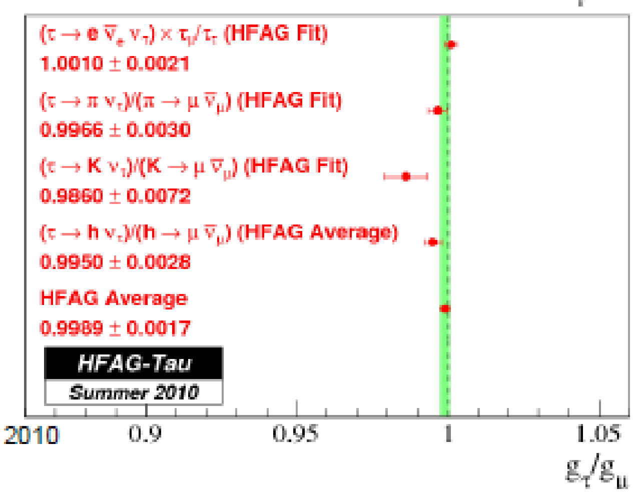
$|V_{us}|$ extracted from τ's



HFAG: arXiv:1010.1589

Charged Lepton Universality from τ's





$|V_{us}| \times f_+(0)$

C. Bloise LNF-INFN

Vus determined from kaon, hyperon, and τ decays
The most precise measurement from K_{l3} decays

$$\Gamma(K_{l3}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+(0)|^2 I_{K,l}(\lambda)(1 + 2\Delta_K^{SU(2)} + 2\Delta_{K,l}^{EM})$$

Branching fractions, lifetimes
Dalitz plot analysis to obtain $I_{K,l}(\lambda)$

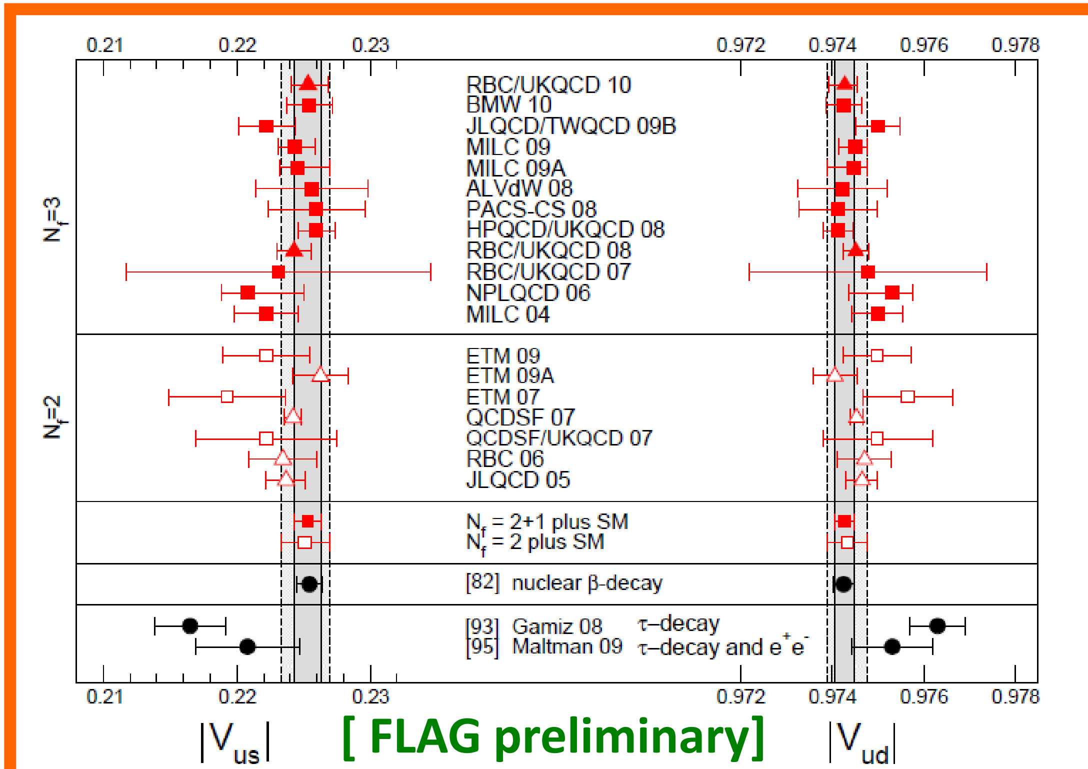
$K^{\pm}$ semileptonic branching fractions

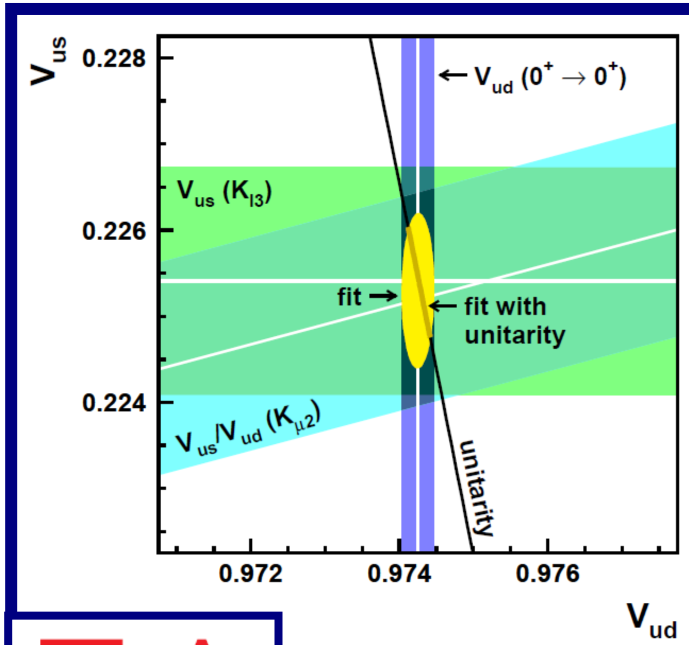
Measurements

BNL-E865	$BR(K_{e3})/BR(\pi\pi^0+K_{\mu3}+\pi\pi^0\pi^0)$	0.1962(36)
NA48/2	$BR(K_{e3})/BR(\pi\pi^0)$	0.2470(10)
NA48/2	$BR(K_{\mu3})/BR(\pi\pi^0)$	0.1637(7)
KLOE	$BR(K_{e3})$	0.04965(53)
KLOE	$BR(K_{\mu3})$	0.03233(39)

The 1st row unitarity test

Vittorio Lubicz





FlaviA net Kaon WG

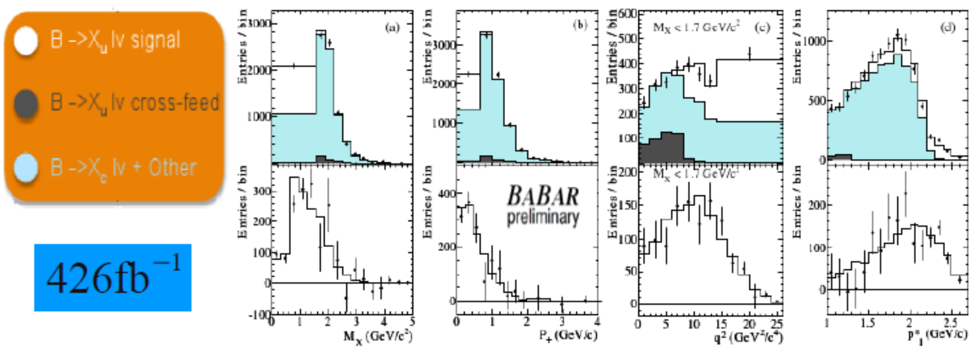
Combining with $|V_{ud}|$ from nuclear β decays

- $|V_{us}|_{Kl3} = 0.2263(20)$
- $|V_{us}|_{Kl3+Kl2} = 0.2255(14)$
- $|V_{us}|_{Kl2} = 0.2247(19)$
- $|V_{us}|_{Unitar.} = 0.2254(10)$

$$\Delta_{CKM} = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1 = (0 \quad 8)\cdot 10^{-4}$$

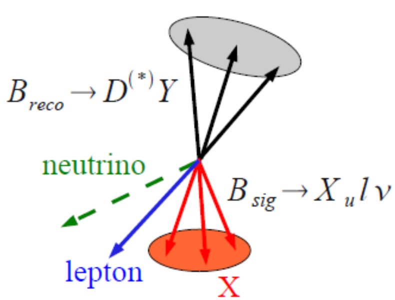
V_{ub} from inclusive $B \to X_u l\nu$ decays

New BaBar recoil analysis: results



	Signal yield	$\Delta\mathcal{B}(\bar{B} \to X_u \ell \bar{\nu})$ (10^{-3})
$M_X < 1.55$	$1033 \pm 73_{stat}$	$1.08 \pm 0.08_{stat} \pm 0.06_{sys}$
$M_X < 1.70$	$1089 \pm 82_{stat}$	$1.15 \pm 0.10_{stat} \pm 0.08_{sys}$
$P_+ < 0.66$	$902 \pm 80_{stat}$	$0.98 \pm 0.09_{stat} \pm 0.08_{sys}$
$M_X < 1.70$ and $q^2 > 8$	$665 \pm 53_{stat}$	$0.68 \pm 0.06_{stat} \pm 0.04_{sys}$
(M_X, q^2), $p^*_\ell > 1.0$	$1441 \pm 102_{stat}$	$1.80 \pm 0.13_{stat} \pm 0.15_{sys}$
$p^*_\ell > 1.0$	$1462 \pm 137_{stat}$	$1.76 \pm 0.16_{stat} \pm 0.18_{sys}$
$p^*_\ell > 1.3$	$1326 \pm 118_{stat}$	$1.50 \pm 0.13_{stat} \pm 0.14_{sys}$

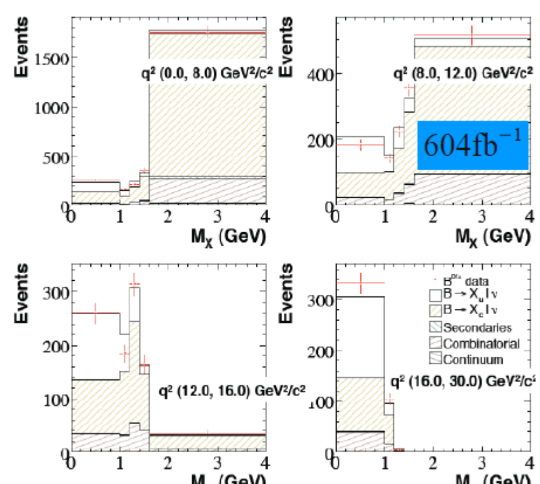
13



Nicola Gagliardi

- New BaBar recoil analysis;
- Belle multivariate analysis;

Belle recoil analysis: results



$\sim 1035\, B \to X_u l \nu$ *events*

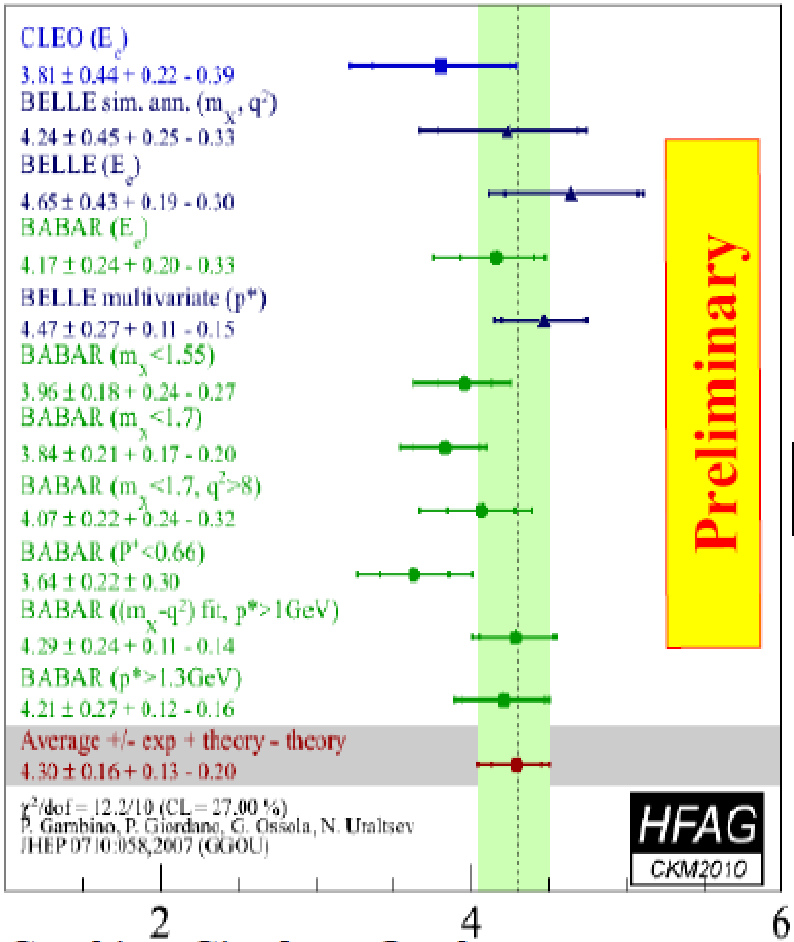
$p_\ell^{*B} > 1.0$ GeV	$\Delta\mathcal{B}/\mathcal{B}$ (%)
$\mathcal{B}(D^{(*)}\ell\nu)$	1.2
$(D^{(*)}\ell\nu)$ form factors	1.2
$\mathcal{B}(D^{**}e\nu)$ & form factors	0.2
$B \to X_u\ell\nu$ (SF)	3.6
$B \to X_u\ell\nu$ $(g \to s\bar{s})$	1.5
$\mathcal{B}(B \to \pi/\rho/\omega\ell\nu)$	2.3
$\mathcal{B}(B \to \eta, \eta'\ell\nu)$	3.2
$\mathcal{B}(B \to X_u\ell\nu)$ un-meas.	2.9
Cont./Comb.	1.8
Sec./Fakes/Fit	1.0
PID/Reconstruction	3.1
BDT	3.1
Systematics	8.1
Statistics	8.8

PRL 104:021801 (2010)

$$\Delta B(B \to X_u l \nu;\, p_l > 1.0\, GeV) = 1.963 \times (1 \pm 0.088_{stat} \pm 0.081_{syst}) \times 10^{-3}$$

Nicola Gagliardi

$|V_{ub}|$ results (HFAG average, GGOU)



Gambino, Giordano, Ossola, Uraltsev JHEP0710:058(2007)

$$|V_{ub}| = \sqrt{\frac{\Delta B(B \to X_u l \nu)}{\Gamma_{thy} \cdot \tau_B}}$$

- Acceptances provided by many different theoretical models;
- Many $|V_{ub}|$ values.

$|V_{ub}|$=(4.30±0.16+0.13-0.20)x10^{-3}

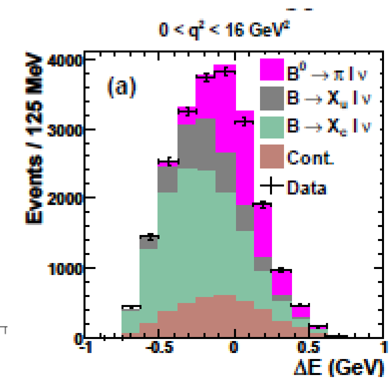
δ|Vub|	+4.9% -6.3%
Statistical	2.3%
Exp.systematics	1.9%
$b \to c \ell \nu$ model	1.2%
$b \to u \ell \nu$ model	1.6%
Non pert.-	1.5%
Higher order par.	2.5%
q^2 tail model	1.7%
Weak Annihilation	-3.9%

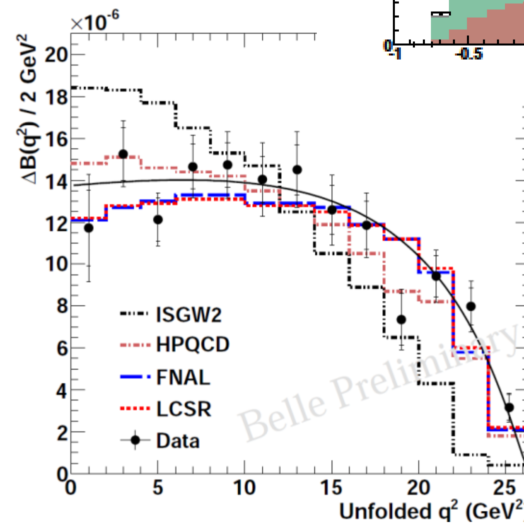
V_{ub} from B exclusive decays

Isamu NAKAMURA

$B^0 \to \pi^- \ell^+ \nu$ untagged 其ノ六

Belle Preliminary





- V_{ub} can be extracted from the partial Branching Fraction,

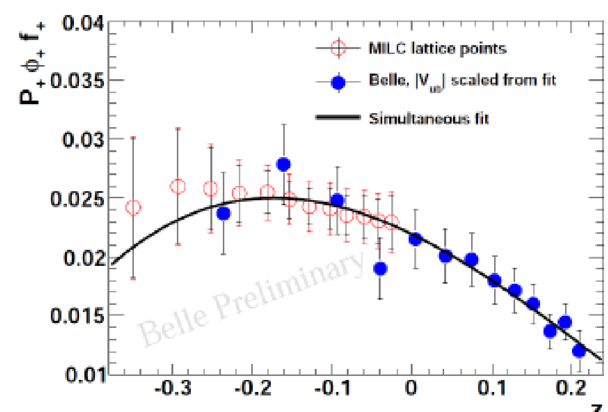
$$|V_{ub}| = \sqrt{\Delta\mathcal{B}(q^2)/\tau_{B^0}\Delta\zeta},$$

where,
$\Delta\zeta$: form factor in corresponding q^2 range

- Result

	q^2 (GeV^2)	$\Delta\zeta$ (ps^{-1})	$\lvert V_{ub}\rvert(10^{-3})$
HPQCD	> 16	2.07 ± 0.57	$3.55 \pm 0.09 \pm 0.09^{+0.62}_{-0.41}$
FNAL	> 16	1.83 ± 0.50	$3.78 \pm 0.10 \pm 0.10^{+0.65}_{-0.43}$
LCSR	< 16	5.4 ± 1.4	$3.64 \pm 0.06 \pm 0.09^{+0.60}_{-0.40}$
ISGW2	all	9.6 ± 4.8	$3.19 \pm 0.04 \pm 0.07^{+1.32}_{-0.59}$

- Form factor uncertainties largest contribution



- F.F. model independent V_{ub} extraction method (PRD79054507 (2009))

$$|V_{ub}| = (3.43 \pm 0.33) \times 10^{-3}$$

Vittorio Lubicz

Exclusive vs Inclusive Vub

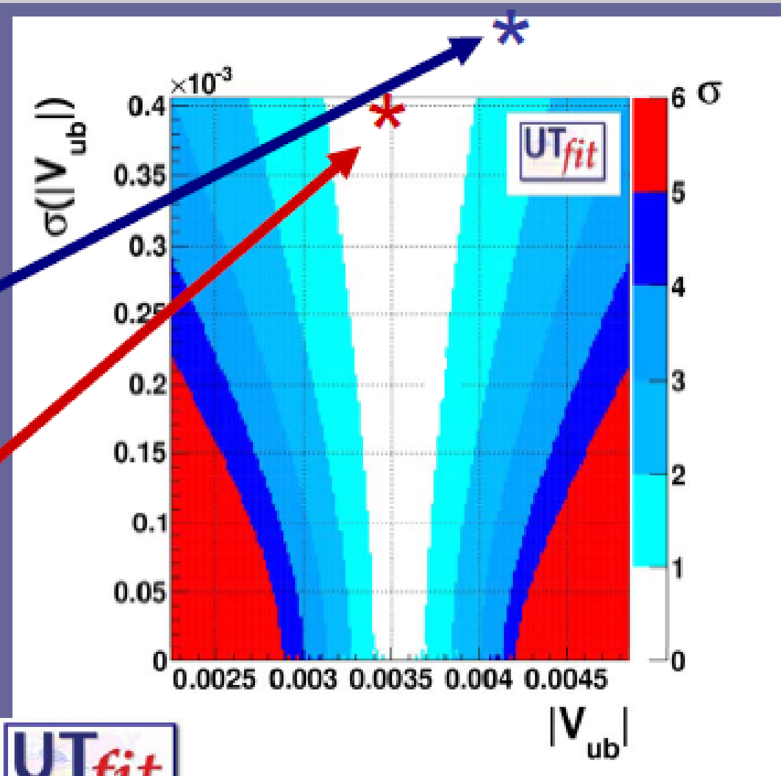
- The uncertainty of inclusive Vub estimated from the spread among different models. This is questionable

- The fit in the SM favors a low value of Vub, as indicated by exclusive decays

$|V_{ub}|_{incl.} = (42.0 \pm 1.5 \pm 5.0)\ 10^{-4}$

$|V_{ub}|_{excl.} = (35.0 \pm 4.0)\ 10^{-4}$

- Improve the accuracy of exclusive Vub in order to clarify the issue (see $D \to \pi/K\ l\nu$)



UTfit

$|V_{ub}|_{SM\text{-}Fit} = (35.5 \pm 1.4)\ 10^{-4}$

V_{cb} from $B \rightarrow X_c l\nu$ inclusive decays

Kyle J. Knoepfel

$B \rightarrow X_c \, l \, \nu$ Measurements

BELLE

- **Hadronic X_c mass moments (k = 1 – 6)**

$$\langle M_X^k \rangle = \frac{\sum_i (M_X^k)_i N_i}{\sum_i N_i} \qquad \sigma^2 \left[\langle M_X^k \rangle \right] = \frac{\sum_{i,j} (M_X^k)_i X_{ij} (M_X^k)_j}{\left(\sum_i N_i\right)^2}$$

$$\langle (M_X^2 - \langle M_X^2 \rangle)^2 \rangle$$

- **Mixed mass/energy moments (k = 2, 4, 6)**
  - **Gambino & Uraltsev:** Eur. Phys. J. C **34**, 181 (2004)

$$n_X^2 = M_X^2 c^4 - 2\tilde{\Lambda} E_X + \tilde{\Lambda}^2$$

- **Fitting method to extract SM & QCD parameters:**
  - **Buchmüller & Flächer:** PRD **73**, 073008 (2006)
  - **B. Aubert *et al.***: PRL **93**, 011803 (2004)

$B \to X_s\gamma$: absolute BR and A_{cp}

- $B \to X_s\gamma$ decays are sensitive to new physics through new physics particles propagating in penguin diagram
  - Branching fraction result from Belle consistent with SM
  - New preliminary A_{CP} result from *BABAR* consistent with SM

Kyle J. Knoepfel

$B \to X_{s+d}\,\gamma$ Result

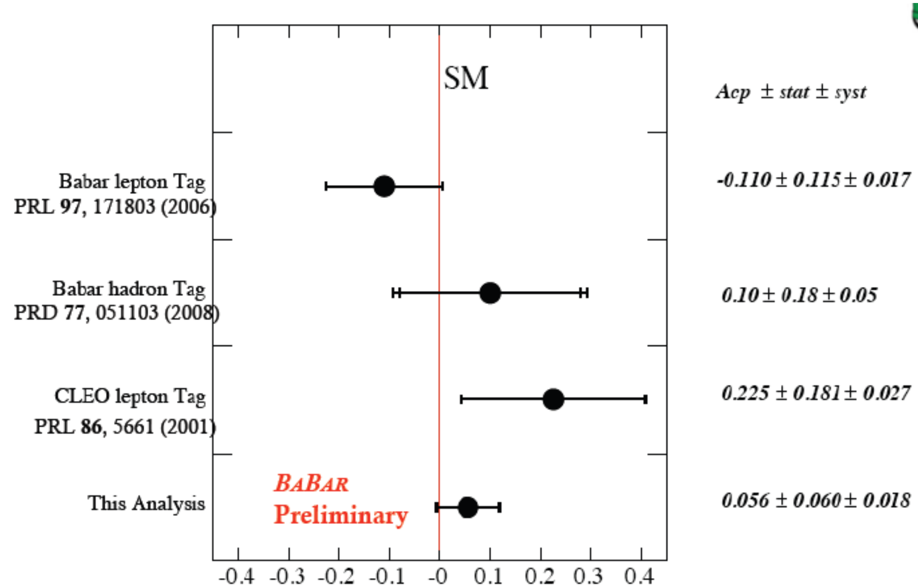
BELLE

$$\mathcal{B}(B \to X_s\gamma)_{E_\gamma > 1.7\ \mathrm{GeV}} = \left(3.45 \pm 0.15_{\mathrm{stat.}} \pm 0.40_{\mathrm{syst.}}\right) \times 10^{-4}$$

- Direct *CP*-Asymmetry – New *BABAR* Result

$$A_{CP}(B \to X_{s+d}\gamma) = \frac{\Gamma(\overline{B} \to \overline{X}_{s+d}\gamma) - \Gamma(B \to X_{s+d}\gamma)}{\Gamma(\overline{B} \to \overline{X}_{s+d}\gamma) + \Gamma(B \to X_{s+d}\gamma)}$$

$$A_{CP}^{SM}(B \to X_{s+d}\gamma) \sim 10^{-6}$$

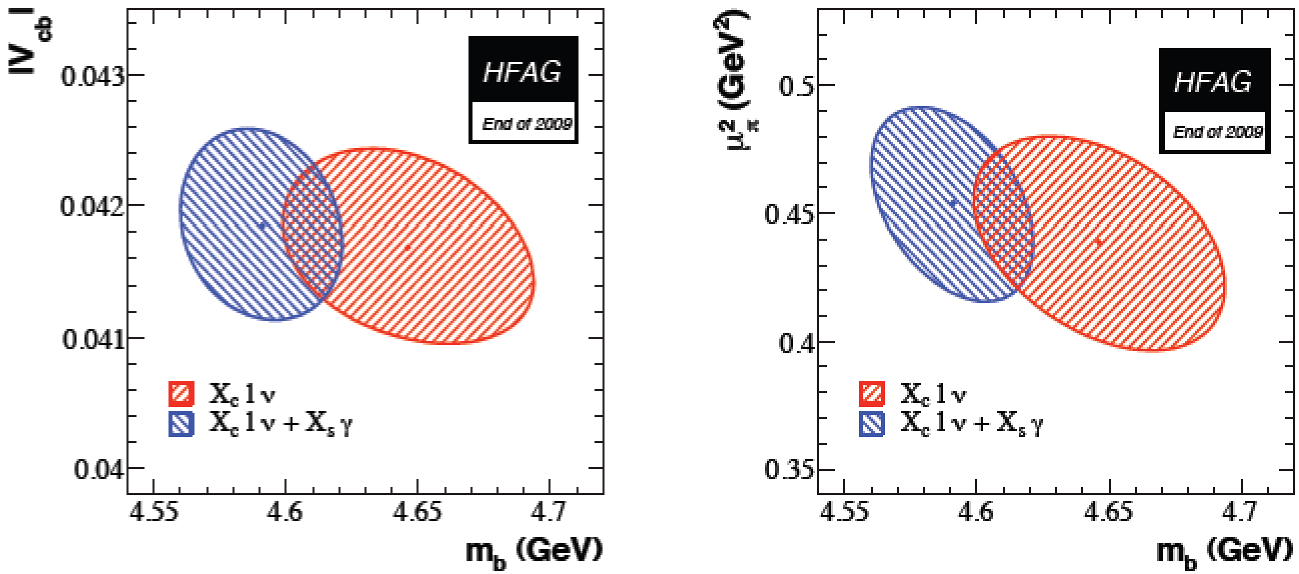


$B \rightarrow X_c l\nu$ and $B \rightarrow X_s\gamma$

Kyle J. Knoepfel

Heavy Flavor Averaging Group (HFAG) Fit

- **Measurements from multiple collaborations used to calculate V_{cb}, m_b and μ_π^2**

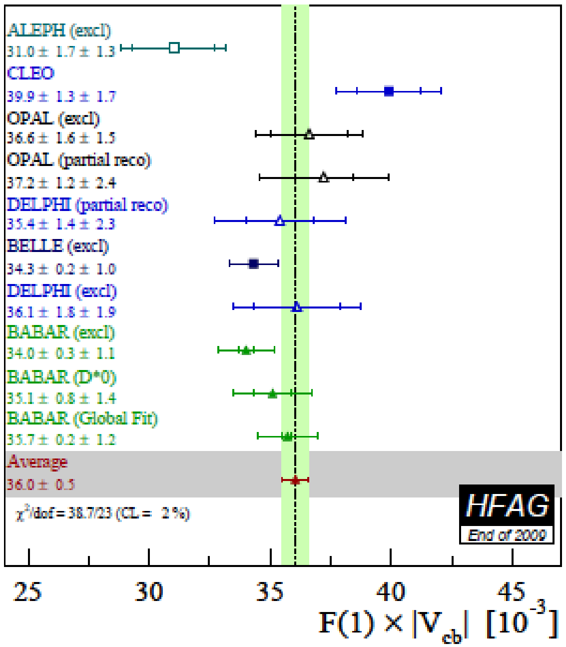


- **Tension between semi-leptonic results and SL+ radiative penguin results—source of much discussion**

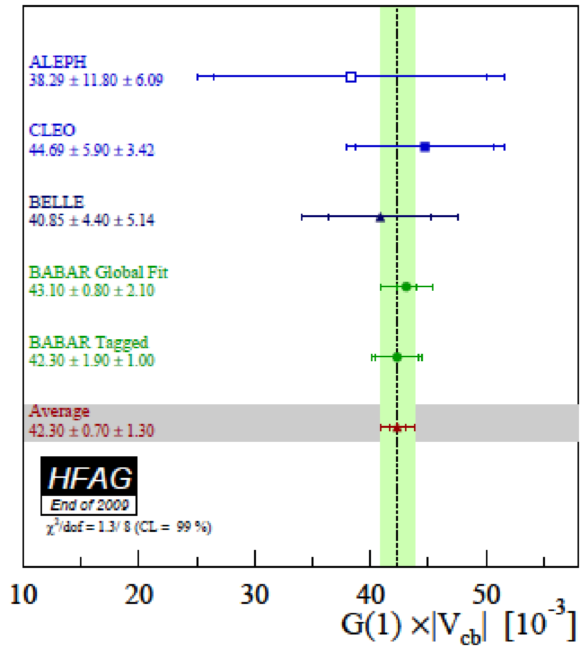
V_{cb} from B exclusive decays

Isamu NAKAMURA

Exclusive $B \to D^* \ell \nu$



Exclusive $B \to D \ell \nu$



- Exclusive V_{cb}

	$(\mathcal{F}(1),\mathcal{G}(1))\lvert V_{cb}\rvert \times 10^{-3}$	$\mathcal{F}(1),\mathcal{G}(1)$	$\lvert V_{cb}\rvert \times 10^{-3}$
$B \to D^* \ell \nu$	36.0 ± 0.5	0.91 ± 0.02	36.7 ± 0.8
$B \to D \ell \nu$	42.3 ± 1.5	1.07 ± 0.02	39.4 ± 1.6

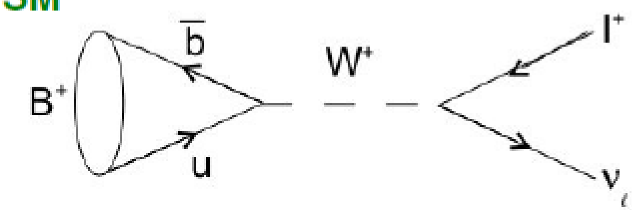
- V_{cb} inclusive

$$|V_{cb}| = (41.9 \pm 0.7) \times 10^{-3}$$

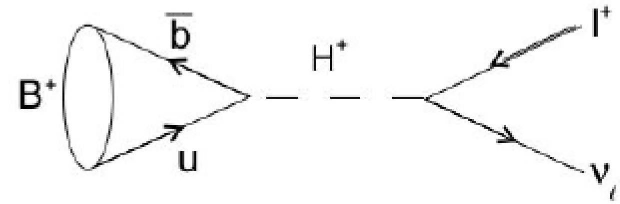
>2 σ

$B^+ \to l^+ \nu$: Theoretical Motivation

SM



New Physics



$$Br(B \to l \nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

- Expected BR ~10^{-4} for $B^+ \to \tau^+ \nu$
- Much smaller for
  - $B^+ \to \mu^+ \nu$ (~10^{-7})
  - $B^+ \to e^+ \nu$ (~10^{-11})

  due to **helicity suppression**
- Latest analyses use up to 468M (BaBar) and 657M (Belle) BB pairs

- New Physics (NP) contributions can significantly enhance the rate

$$Br(B \to l\nu) = B_{SM} \times r_H$$

- 2HDM

(W. S. Hou, PRD 48 (1993) 2342)

$$r_H = \left(1 - \tan^2\beta \frac{m_B^2}{m_H^2}\right)^2$$

- SUSY

(A. G. Akeroyd et al., J. Phys G 29 (2003) 2311)

$$r_H = \left(1 - \frac{\tan^2\beta}{1 + \bar{\epsilon}_0 \tan\beta} \frac{m_B^2}{m_H^2}\right)^2$$

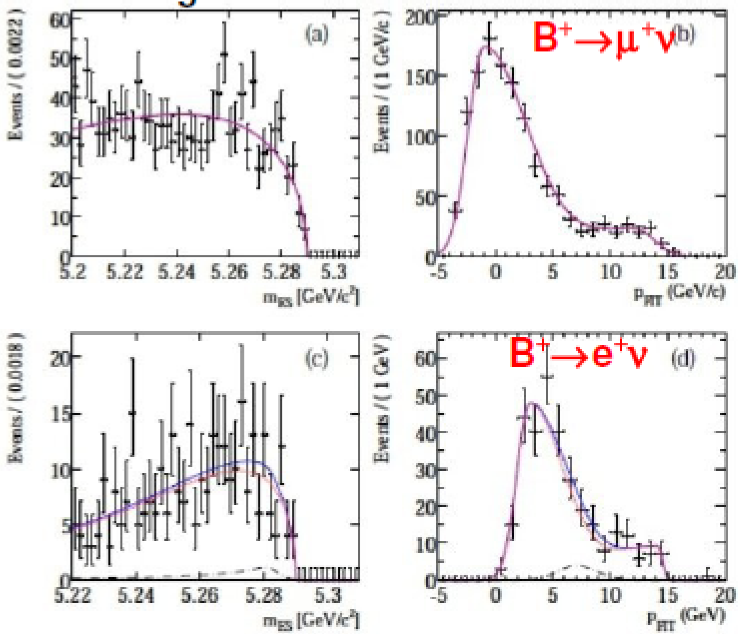
Alejandro Pérez

$B^+ \to e^+\nu$ and $B^+ \to \mu^+\nu$

BaBar Hadronic tag

Reconstructed Btag mass

Lepton p(c.m.) and p'(Bsig-CM) Fisher



- Total PDF
- Background PDF
- Signal PDF

- No events seen. All upper limits (90% C.L.) above SM value
- BaBar hadronic tag:

Phys.Rev.D79:091101, 2009.
arXiv:0903.1220

- Br($B^+ \to e^+\nu$) < 1.9×10^{-6}
- Br($B^+ \to \mu^+\nu$) < 1.0×10^{-6}

- BaBar semileptonic tag:

Phys.Rev.D81:051101, 2010.
arXiv:0809.4027

- Br($B^+ \to e^+\nu$) < 0.8×10^{-5}
- Br($B^+ \to \mu^+\nu$) < 1.1×10^{-5}

- Belle report the limits:

Phys.Lett. B 646, 67 (2007)

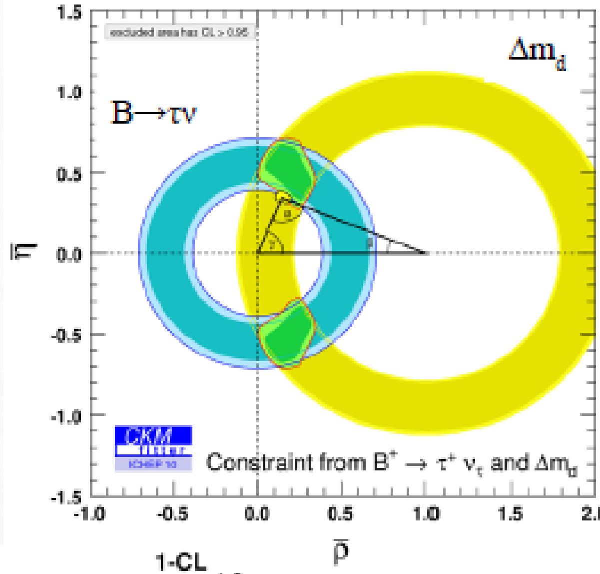
- Br($B^+ \to e^+\nu$) < 0.98×10^{-6}
- Br($B^+ \to \mu^+\nu$) < 1.70×10^{-6}

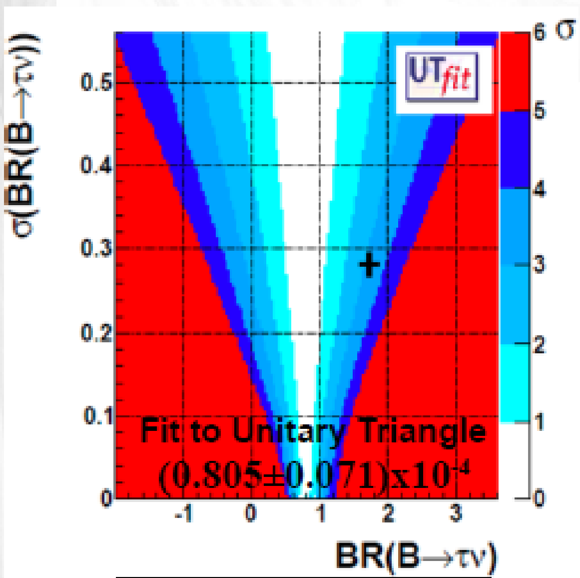
$B\to\tau\nu$: Comparison of Results

	$\mathcal{B}(B\to\tau\nu)$
Belle (combined)	$(1.62\pm0.40)\times10^{-4}$
BaBar (combined)	$(1.76\pm0.49)\times10^{-4}$
HFAG Ave (Aug'10)	$(1.64\pm0.34)\times10^{-4}$
Standard Model	$(1.2\pm0.25)\times10^{-4}$

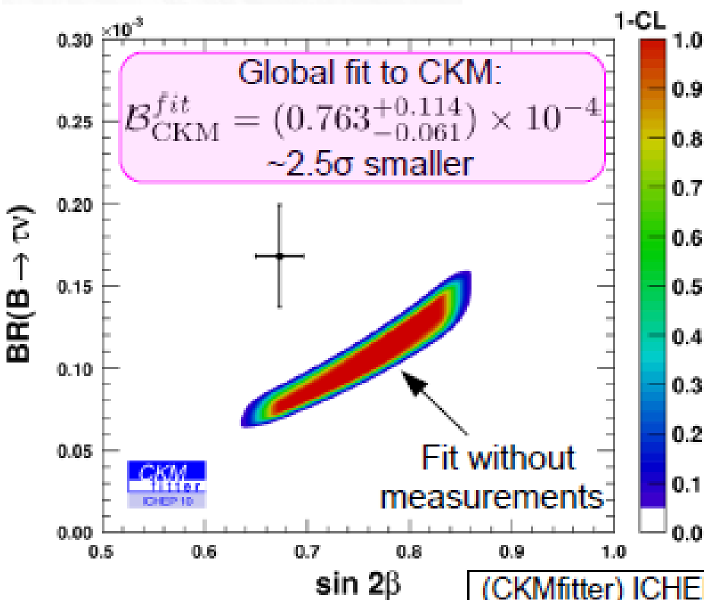
(V_{ub}=(4.32±0.3)x10⁻³, f_B=190±13MeV)

SM prediction is ~2σ smaller than experiments!





(UTfit) Tarantino, ICHEP10, update of arXiv:0908.3470

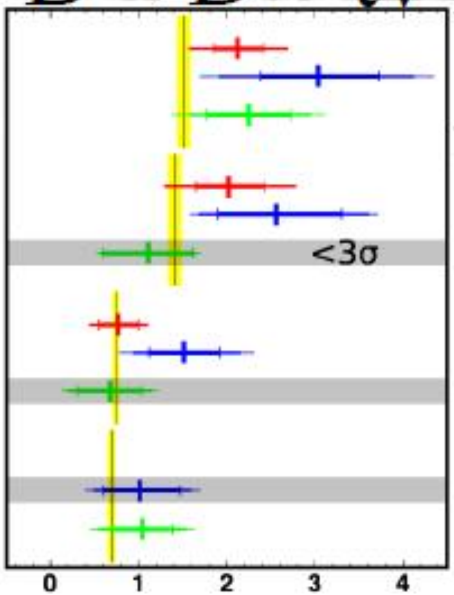


(CKMfitter) ICHEP10

Possible sources of CKM discrepencies:
- Stat. Fluctuations in measurements
- Lattice estimate of f_B
- New Physics in $B\to\tau\nu$ or sin(2β)

Dana Lindemann

$B \to D^{(*)}\tau\nu$ Comparison of Results



Mode	Belle Inclusive / Belle Hadronic / BaBar Hadronic
$B^+ \to \overline{D}^{*0}\tau^+\nu_\tau$	$[2.12^{+0.28}_{-0.27} \pm 0.29]\%$ 8.1σ
	$[3.04^{+0.69}_{-0.66}{}^{+0.40}_{-0.47}]\%$ 3.9σ
	$[2.25 \pm 0.48 \pm 0.22]\%$ 5.3σ
$B^0 \to D^{*-}\tau^+\nu_\tau$	$[2.02^{+0.40}_{-0.37} \pm 0.37]\%$ 5.2σ
	$[2.56^{+0.75}_{-0.66}{}^{+0.31}_{-0.22}]\%$ 4.7σ
	$[1.11 \pm 0.51 \pm 0.04]\%$ 2.7σ
$B^+ \to \overline{D}^0\tau^+\nu_\tau$	$[0.77 \pm 0.22 \pm 0.12]\%$ 3.5σ
	$[1.51^{+0.41}_{-0.39}{}^{+0.24}_{-0.19}]\%$ 3.8σ
	$[0.67 \pm 0.37 \pm 0.11]\%$ 1.8σ
$B^0 \to D^-\tau^+\nu_\tau$	$[1.01^{+0.46}_{-0.41}{}^{+0.13}_{-0.11}]\%$ 2.6σ
	$[1.04 \pm 0.35 \pm 0.15]\%$ 3.3σ

– Belle Inclusive

PRL99, 191807 (2007)
arXiv:1005.2302(2010)

– Belle Hadronic

arXiv:0910.4301 (2009)

– BaBar Hadronic

PRD79, 092002 (2009)
PRL100, 021801 (2008)

– Standard Model

Chen &Geng,
JHEP 0610, 053 (2006)

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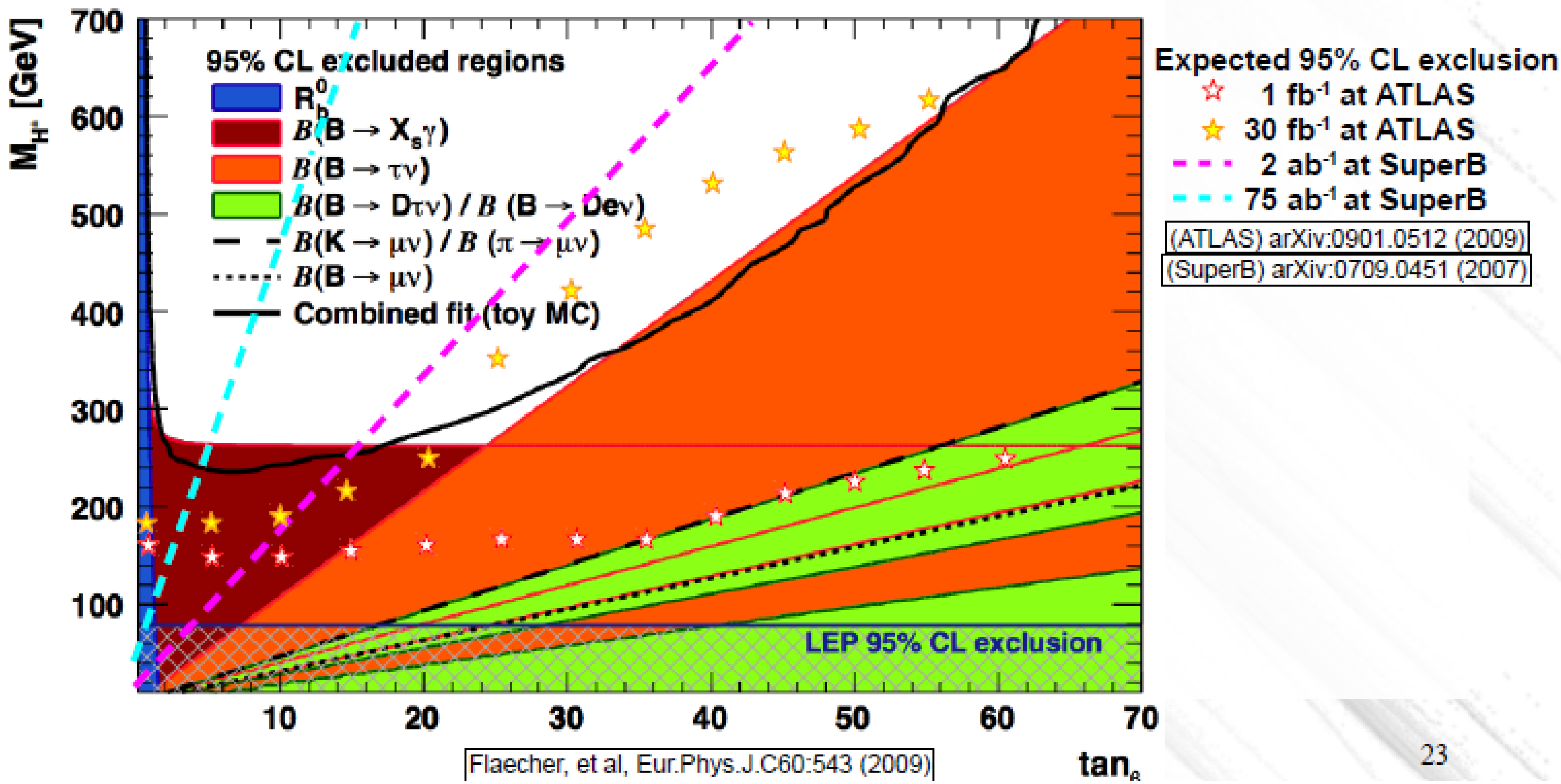
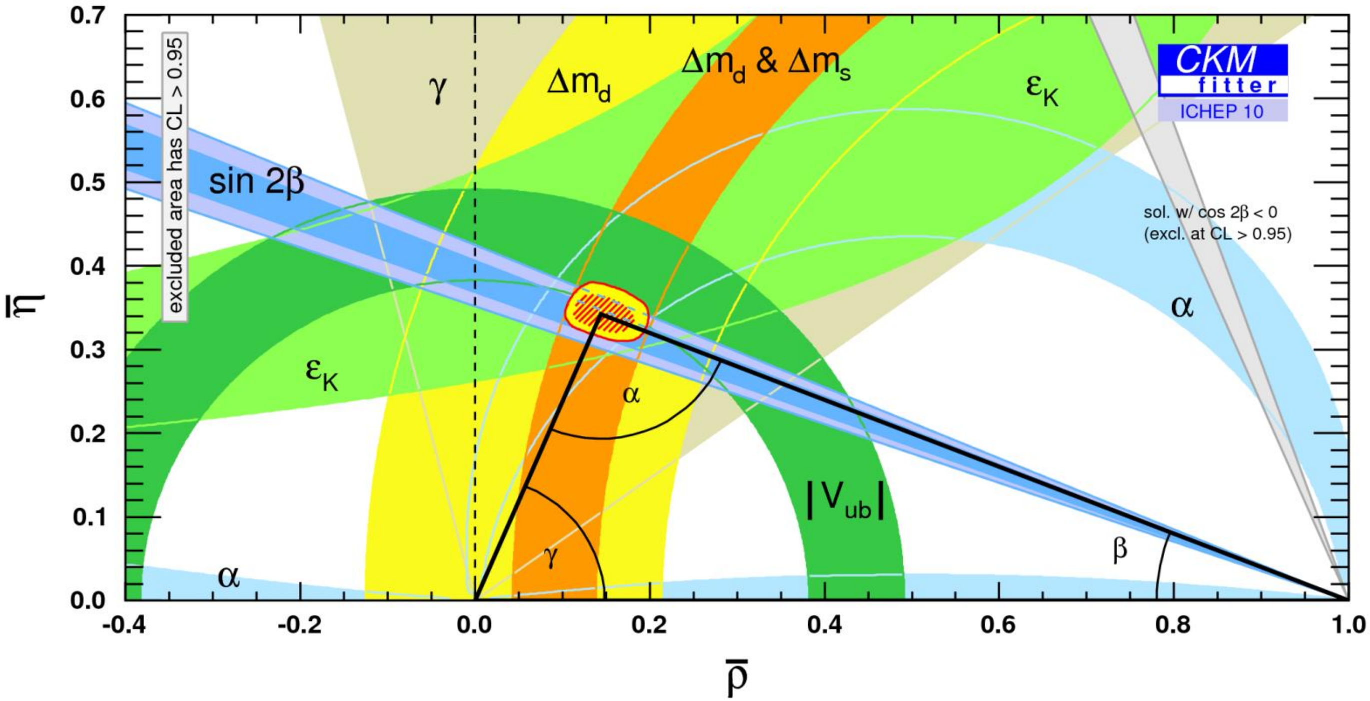
Conclusions

- B→τν and B→D$^{(*)}$τν: now well-established decays, observed at both BaBar and Belle
- B→μν and B→ℓνγ: not yet observed, but sensitivity near SM expectations! Observations expected at next generation B-factories
- Measured BFs and SM expectations consistent within uncertainties, but room for NP!
- B→τν and B→Dτν already provide exclusion in plane of 2HDM parameters m_H x tanβ. B-factory sensitivity is competitive with direct searches at LHC!



Flaecher, et al, Eur.Phys.J.C60:543 (2009)



Mesurement of CKM elements has reached excellent precision.
But still open space for new results to lead to NP discovery.